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Sensitive Elements of Magnetic Field Sensors Formation as Spin-Valve Type Multilayer Structures Based on Co and Cu

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In this paper proposed a method of forming the sensitive elements of sensors magnetic field as a spin-valve type multilayer structures based on Co and Cu. Presents the results of the study their magnetoresistive properties. It is shown that the spin-valve structure such as Co/Cu/Cu works most efficiently with a thickness of intermediate layer Cu 8 nm and the thickness of the magnetic layers 6 nm (top) and 20 nm (bottom).

Keywords: Film system, Spin valve, Sensitive elements, Sensor of magnetic field, Magnetoresistance

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1. INTRODUCTION

There are many devices detection and measurement of the magnetic field, which makes them widely used in many industries [1]. Widespread, use of these sensors require improvement of the existing base material for the realization of their sensitive elements. It has become a popular production of elements sensitive magnetic field sensors in a multi-layer system in which the phenomenon of giant magnetic field that can be conditionally divided into several groups [2], among them - type superlattice Fe/Cr [3-4], where the magnetic layers are antiferromagnetic arranged through the magnetic layer and the spin-valve structure [5-6], in which layers reversal due to different coercive force of layers or the presence of one of the layers of unidirectional anisotropy (magnetic bias). Spin valve (simplest) consists of two magnetic layers separated by a nonmagnetic layer, but the magnetic moment of one of the layers is fixed with a fixed direction of the magnetic moment [7]. At the same time, the magnetization of the other layer can easily be changed by an external magnetic field.

In [8-9] presented the results of research magnetoresistive properties of spin-valve structures were obtained in the form of multilayer films based on Co and Cu. In this paper proposed to use such multilayer structures spin-valve type based on Co and Cu as sensitive elements of magnetic field sensors.

2. EXPERIMENT

The experiments have been performed under high vacuum condition (the base pressure was 10^{-4} Pa) and samples have been prepared by method of thermal evaporation on substrates at temperature $T_s = 460$ K. For all samples preparation condition were the same.

The sensing element sensors magnetic field were obtained in the form of multilayer film structures spin-valve type Co(x)/Cu(6)/Co(20)/Cr(6)/S (S – substrate, thickness in nm) and Co(6)/Cu(x)/Co(20)/Cr(6)/S. In the first case, changed the thickness of the top layer of Co x, and in the other non-magnetic layer thickness Cu. For microscopic and electron-graphic studies as substrates used carbon film thickness of 20 nm, deposition on NaCl crystal and prepared for microscopic mesh. The amorphous carbon structure is transparent to the electron beam and has no effect on the phase state of the films. To investigate other properties used ceramics plate (amorphousAl_2O_3).

In the film samples of all series upper sensor (magnetic and soft) Co layer required for easy changes of magnetization under the influence of an external magnetic field. An intermediate layer of Cu provides separation of ferromagnetic layers and serves to transition electrons in the process spin-dependent scattering. Hard magnetic layer of Co provides a fixed magnetic moment. Cr buffer layer is needed to ensure better adhesion of the resulting film to the substrate, and to smooth the surface of the substrate on receipt Co bottom layer, because the lining of ceramics has rough surface. For a wide range of results concerning the magnetoresistive properties was made variation thickness sensitive layer Co. Also, changes the value of the intermediate layer (non-magnetic) and the relative position of the magnetic layers.

The thickness of precipitable film samples was controlled by a quartz resonator. An important aspect was the constant compliance rate of condensation. It is known that the increase in the rate of condensation leads to a decrease in the average crystallite size, and found that the lattice parameter is also reduced. In our experiments we used a constant value of the condensation rate for all films $\omega = 0{,}1$ nm/s, which makes it possible to obtain pure film materials.

The first series of samples had fixed thickness of non-magnetic layer d_{Cu} = 6 nm and consisted of film, the following systems: Co(4)/Cu(6)/Co(20)/Cr(6)/S Co(6)/Cu(6)/Co(20)/Cr(6)/S; Co(8)/Cu(6)/Co(20)/Cr(6)/S.

The second series of samples had fixed thickness of the soft magnetic layer $d_{Co} = 6$ nm and consisted of the following film systems: Co(6)/Cu(4)/Co(20)/Cr(6)/S; Co(6)/Cu(6)/Co(20)/Cr(6)/S; Co(6)/Cu(8)/Co(20)/Cr(6)/S.

Upon receipt of samples and studies of their magnetoresistive properties were investigated the effect of temperature on the sensing element of the sensor's magnetic field. This has been realized by thermal annealing of samples in a vacuum chamber. As a result, there were two cycles of annealing at a temperature of 609 K and 850 K. Exposure at these temperatures was 12-15 minutes, then began gradual cooling of the sample to the initial temperature.

The resistance R of the samples in the magnetic field B was measured in standard in-plane geometry with current and magnetic field lying in longitudinal transverse and perpendicular geometries. The value of magnetoresistance (*MR*) as function of the field has been defined as $MR = (R(B)\text{-}R(B_s)/R(B_s))\cdot 100\%$, where $R(B_s)$ is saturation field. According to the obtained values of the MO of the magnetic field are constructed matching dependencies and calculated magnetic sensitivity of spin-valve systems, which is as:

$$S_B = \left| \frac{(\Delta R / R(B_S))_{\max}}{\Delta B} \right|, \qquad (1)$$

when $(\Delta R / R(B_S))_{\max}$ - maximum value of magnetoresistance; ΔB - change of saturation magnetic induction (or maximum value) B_s to demagnetization [5]. Note that the value of magnetic sensitivity of the sensing element of the sensor's magnetic field fully defines the area of application.

3. RESULT

Dependence of the magnetoresistance on the annealing temperature for multilayered film systems of spin-valve type based on Co and Cu from the first and second series are presented in Fig. 1. As can be seen from Fig. 1 the magnitude of the magnetoresistance of samples changes after exposure to high temperatures.

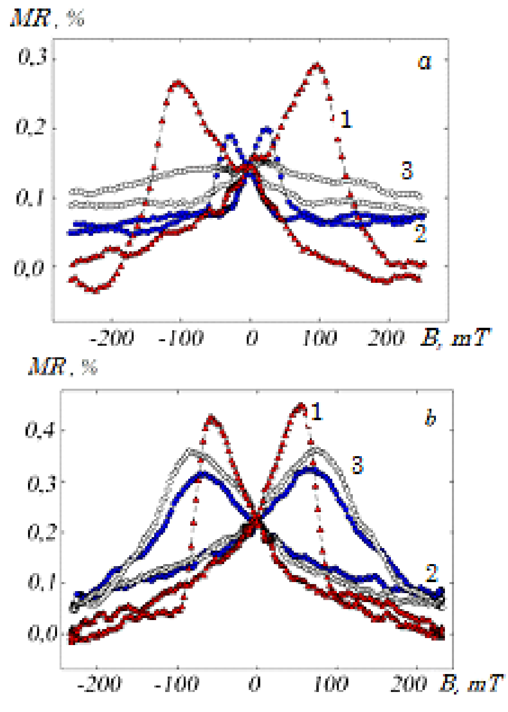

Fig. 1 – MR of multilayer film systems Co(6)/Cu(6)/Co(20)/Cr(6)/S (a) and Co(6)/Cu(8)/Co(20)/Cr(6)/S (b) not annealed (2) and after annealing to T = 609 K (3) and 850 K (1)

May be noted that observed an increase in the relative value of resistance of the sample in a magnetic field which in turn has affected the magnetic sensitivity of each of the spin-valves. The results of calculation of the magnetic sensitivity ratio (1) for the first series of samples with a fixed thickness of nonmagnetic Cu layer 6 nm are presented in Table 1.

The next step was to study the dependence of the magnetoresistance on the thickness of non-magnetic layer and the soft magnetic layer at a certain temperature value. This makes it possible to predict the behavior of the spin-valve in a magnetic field by the selection one or another layer thickness, determined the specific purpose of the sensitive element Simply put, we are talking about the magnetic field, to be able to fix the sensitive elements of sensors magnetic field.

Comparison magnetoresistive properties of both series of samples without annealing can be done by Fig. 2. Results of calculations for a series of fixed-layer Co 6 nm are presented in Table 2.

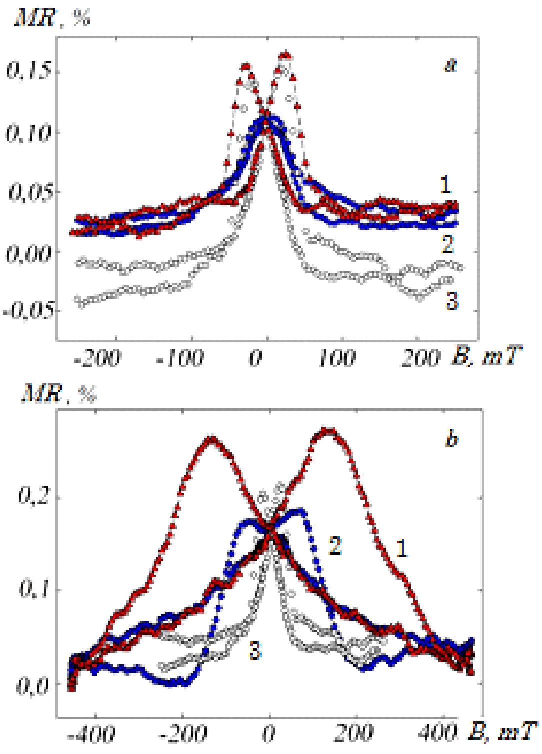

Fig. 2 – MR of multilayer film systems the first series (a): not annealed Co(4)/Cu(6)/Co(20)/Cr(6)/S (2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (3), Co(8)/Cu(6)/Co(20)/Cr(6)/S (1) and the second series (b): Co(6)/Cu(4)/Co(20)/Cr(6)/S(2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (1), Co(6)/Cu(8)/Co(20)/Cr(6)/S (3)

Based on these dependencies, we can say that the change in the thickness of the soft magnetic layer of Co 4 to 8 nm leads to fluctuations in the value MR and causes a decrease, but at the same time an increase in the magnetic sensitivity. This can be explained due to the fact that with increasing Co layer thickness, greater strength of the applied external magnetic field to flux reversal this top layer. As a result the dependence becomes more pronounced and has more stable properties. As for the second series, when changing the thickness of non-magnetic layer, there can be talk about a gradual increase in the magnitude of the magnetic sensitivity MR at the same time.

Table 1 – Calculation of the magnetic sensitivity of the samples with a fixed thickness of 6 nm Cu

The structure of the spin-valve	T, K	δ, %	Δ*B*, mT	$S_B \cdot 10^4$, %/mT
Co(4)/Cu(6)/Co(20)/Cr(6)/S	436	0,092	170	5,4
	609	0,135	290	4,6
	850	0,061	70	8,7
Co(6)/Cu(6)/Co(20)/Cr(6)/S	436	0,171	160	1,1
	609	0,111	110	10,1
	850	0,161	200	8,1
Co(8)/Cu(6)/Co(20)/Cr(6)/S	436	0,122	70	17,4
	609	0,045	110	4,1
	850	0,293	353	8,3

Table 2 – Calculation of the magnetic sensitivity of the samples with a fixed thickness of 6 nm Co

The structure of the spin-valve	T, K	δ, %	Δ*B*, mT	$S_B \cdot 10^4$, %/mT
1	2	3	4	5
Co(6)/Cu(4)/Co(20)/Cr(6)/S	436	0,163	500	3,3
	609	0,114	250	4,6
	850	0,181	350	5,2
Co(6)/Cu(6)/Co(20)/Cr(6)/S	436	0,171	160	1,1
	609	0,111	110	10,1
	850	0,161	200	8,1
Co(6)/Cu(8)/Co(20)/Cr(6)/S	436	0,262	580	4,5
	609	0,305	596	5,1
	850	0,436	570	7,6

The reason for this is the gradual increase in the thickness of the Cu layer from 4 to 8 nm, which provides a significant increase in the magnitude of the reversal in compared to the first series of samples. And you can just explain it, because with increasing thickness of the magnetic layer decreases the influence of magnetic Co layers on top of each other, and as a result applied to the spin-valve magnetic field gradually flux reversal its soft magnetic layer. But at the same time with the conduction electrons need more energy value of their motion to pass a layer of copper. From here also increases the magnitude of the applied magnetic field outside reversal.

A similar situation is observed in samples of both series after annealing to a temperature of 610 K. You can verify this by looking at Fig. 3. As you can see, after annealing to T = 610 K in spin valves in which the thickness of Co increases from 4 to 8 nm, there is a decrease of the MR and the other series (the change in the thickness of non-magnetic layer) increasing the value of MR. Compared with the values of MR at 300 K was an increase in the value MR in both series, which is associated with the process of healing the defects in the crystal structure. That is, we can speak of a stable structure of the entire film.

In Fig. 4 shows the results of the study MR of multilayer film systems of spin-valve type after annealing to a temperature of 850 K.

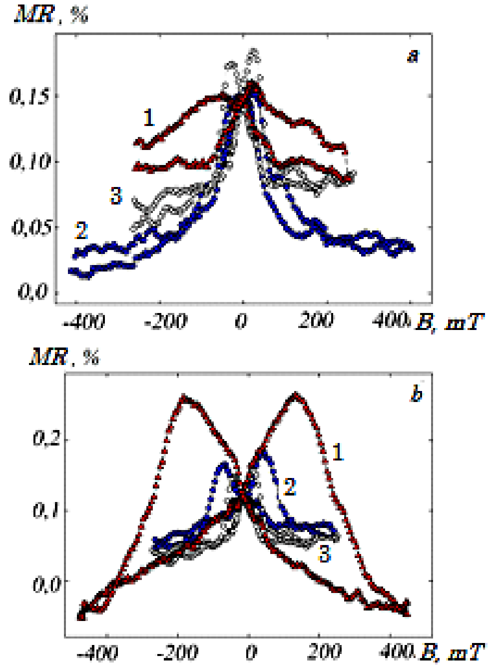

Fig. 3 – MR of multilayer film of the first series (a): Co(4)/Cu(6)/Co(20)/Cr(6)/S (2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (3), Co(8)/Cu(6)/Co(20)/Cr(6)/S (1) and the second series (b): Co(6)/Cu(4)/Co(20)/Cr(6)/S (2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (3), Co(6)/Cu(8)/Co(20)/Cr(6)/S (1) after annealing to T = 610 K

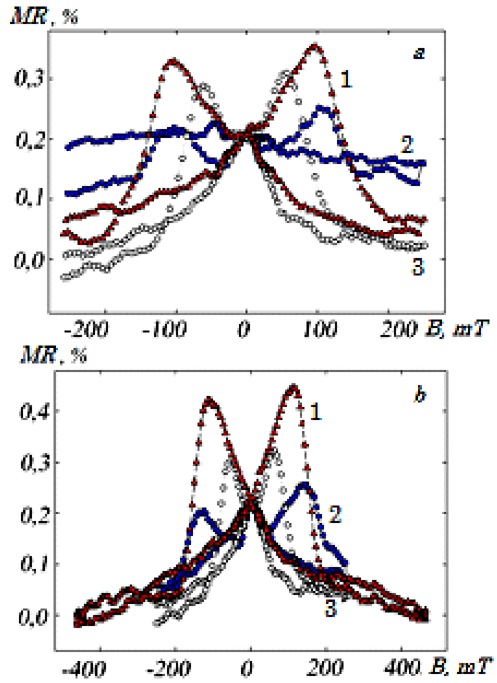

Fig. 4 – MR of multilayer film of the first series (a) Co(4)/Cu(6)/Co(20)/Cr(6)/S (2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (3), Co(8)/Cu(6)/Co(20)/Cr(6)/S (1) and the second series (b): Co(6)/Cu(4)/Co(20)/Cr(6)/S (2), Co(6)/Cu(6)/Co(20)/Cr(6)/S (3), Co(6)/Cu(8)/Co(20)/Cr(6)/S (1) after annealing to T = 850 K

From Fig. 4 can be seen that dependence for both series are similar to the case shown in Fig. 3. : an increase in magnitude with increasing thickness of the MR layer of Co and Cu. Compared with the values of MR after annealing to 610 K was the increase of MR to the values of 0.30 -0.43% respectively.

When using the spin-valve structures as the sensing element of the sensor's magnetic field important position sensor has the ability to respond to a magnetic field applied in any direction. But it is also necessary to pay attention to the magnetic sensitivity, since the detection of small fields necessary a relatively small change in MO, to provide more accurate measurement results. While for other tasks necessary to the contrary a significant sensitivity that will provide a rapid response of the sensor (eg, instant locking/unlocking the electrical circuit in automation and control systems, security systems or biomedical sensors magnetic field).

Therefore, the obtained numerical data for multilayer film systems of spin-valve type, studied in the work we can talk about the prospects of further research magnetoresistive properties to help reduce the thickness of the sensitive magnetic layer and the intermediate layer selection.

Therefore, based on these results, we can talk about the feasibility of a particular spin-valve in varying field of science or technology. Those experimental samples that have a magnetic susceptibility over 8.0%/T, should be used for the detection of magnetic fields in the range from 200 to 600 mT. They have a low rate of magnetic sensitivity for more accurate, safer and less process measurement error. As a result, increasing the resolution, which allows the use of these spin valves as sensitive elements magnetic field sensors for medical, security and other purposes. At the same time, samples that showed the highest value of the magnetic sensitivity can be used in for both analog circuits and digital origin for rapid response to a corresponding change in magnetic flux. It can be used in control systems, automation and control, etc.

4. CONCLUSION

As a result of work has been developed and obtained experimental samples based on the spin-valve is Co/Cu/Co/Cr/S of two types: the first series - multilayer films system with a fixed thickness of non-magnetic layer 6 nm Cu and Co magnetic layer 20 nm (bottom) and a second series - with the thickness of the magnetic layers of Co 6 nm (upper) and 20 nm (bottom). For these systems are characterized by the fact that the functional elements of the first series have relatively low values of MR (0.05-0.29 %) and high values of the magnetic sensitivity of S_B ((4-10)$\cdot 10^4$, %/mT), and samples of the second series is characterized by relatively higher values of MR (0.12-0.44 %) and a lower magnetic susceptibility S_B ((3-8)$\cdot 10^4$, %/mT).

According to a study obtained working parameters functional elements of magnetic field sensors in a multilayer film of spin-valve type can be argued, that film system with the first series should be used in electronic circuits for rapid detection of magnetic fields and processes switching or circuit/unlocking, and based on the multi-layer film of the second series can be realized stable sensor magnetic fields over a wide range (from 200 to 600 mT).

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REFERENCES

1. A.L. H.-May, L.A.A.-Cortes, P.J.G.-Ramirez, E. Manjarrez, *Sensors* **9**, 7785 (2009).
2. Y. Ouyang, J. He, J. Hu, S.X. Wang, *Sensors* **12**, 15520 (2012).
3. R.S. Gaster, L. Xu, S-J. Han, *Nat. Nanotechnol.* **6**,314 (2011).
4. E. Josten, U. Rucker, S. Mattauch, D. Korolkov, A. Glavic, T. Bruckel, *J. Phys.: Conf. Ser.* **211**, 012023 (2010).
5. M. Zhu, C.L. Dennis, R.D.T. McMichael, *Phys. Rev. B* **81**, 140407 (2010).
6. F.K. Dejene, J. Flipse, B. J. S .van Wees, *Phys. Rev. B* **86**, 024436 (2012).
7. I. Bakonyj, L. Peter, *Prog. Mater. Sci.* **55**, 107 (2010).
8. M. Demydenko, S. Protsenko, D. Kostyuk, I. Cheshko, *J. Nano- Electron. Phys.* **3** № 4, 106 (2011).
9. S. Protsenko, I. Cheshko, L. Odnodvorets, *Tech. Phys. Lett.* **35**, No 10, 903 (2009).